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(71) Applicants:
- **PCE Deutschland GmbH**
  59872 Meschede (DE)
- **The Design Bureau "Fizelektronpribor" Ltd**
  Samara 443010 (RU)

(72) Inventor: **RAGAZIN, Denis Nicolaevich**
s. Krasnoselskoye, 446561 (RU)

(74) Representative: **Feder Walter Ebert**
Patentanwälte
Achenbachstrasse 59
40237 Düsseldorf (DE)

(54) MOISTURE METER FOR BULK SOLIDS

(57) The moisture meter for measuring the moisture content of bulk solids comprises a harmonic signal generator which is retuneable in terms of frequency and the control input of which is connected to an electronic control device, a primary transducer formed by an outer shielding conductor and a signal conductor, with the space between said conductors being filed with the material to be measured, a measuring cell which is included between the output of the generator and the input of the primary transducer, and a measuring device which is connected to the control device and the measuring cell. The outer shielding conductor of the primary transducer used is a metallic hopper. The signal conductor is in the form of a small metallic bar, which is mounted inside the hopper and is fixed in openings formed in the walls of said hopper. An insulator consisting of a dielectric is mounted in an opening at a first end of the small bar, and the small bar is connected at its second end to the wall of the hopper. The moisture meter measures the moisture content of bulk solids without taking samples, and ensures an increased level of accuracy and insensitivity to variations in the density of the material at low moisture content levels.

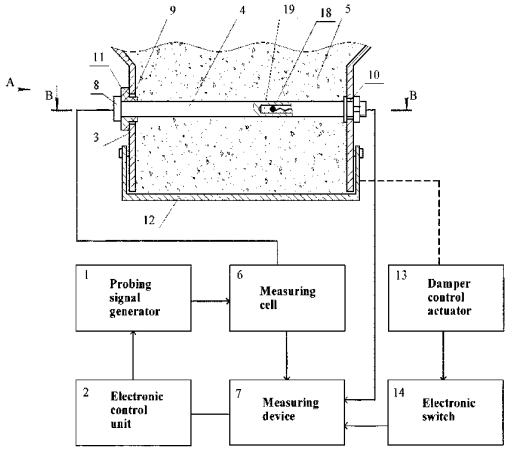

Fig. 1

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Description

[0001] This engineering design belongs to a measuring equipment and may be used in industry to measure percentage of water within ballast, sand, concrete, grain seeds and other bulk materials, and within a technological processing of them.

PRECEDING STATE OF ART

[0002] There is a known moisture meter of bulk materials, which includes a probing microwave signal generator, a ditch where the measuring material is filled in, signal transmission and receiving horn antennas, located on the opposite sides of a ditch, a transducer of a microwave signal into a low-frequency signal, connected to the output of a signal receiving horn antenna and to the measuring device (see Benzar V. K. Technology of UHF moisture measurement. - Minsk: Vysshaya shkola, 1974, pp. 226-234. Бензарь В.К. Техника СВЧ-влагометрии. - Минск: Высшая школа, 1974, с.226-234.).

[0003] In the known moisture meter, moisture content of the material is defined by depletion and phase shift of the probing signal passing through the material. In order to exclude signal scattering on irregularities, particle sizes of the researched material should be smaller than the wavelength. In the known moisture meter, SHF-band microwaves are used, thus it may not be used for measurement of the moisture content of bulk materials such as ballast, rubber chips etc. Moreover, materials with a high moisture content, for example: sand with a mass moisture content >14-16%, can almost completely depress SHF microwave signals, which also limits range of application of the known moisture meter.

[0004] In addition, antennas of the known moisture meters should align with microwave signal's propagation area. During absence of such alignment, probing signal repeatedly reflects on edges from a measuring material to antenna, which leads to errors in measurement of signal depression, as well as errors in definition of the moisture content. This factor may be calculated by matching sizes, material and form of a ditch. Although, if moisture meter's antennas are installed into the industrial hopper, affect of these reflections, including reflections from hopper's walls, increases and error in measurement of moisture content ascends.

[0005] There is a known moisture meter of bulk materials, which includes a probing signal generator, control input of which is connected to the electronic control unit, a primary transducer formed by an outer shielded and signal conductors, inter-space of which is filled with the material to be measured, a measuring cell set between output of a generator and input of the primary transducer, a measuring device connected to the generator's control unit and a measuring cell. (Patent of the Russian Federation for invention No. 2269766).

[0006] Operating principle of the known moisture meter consist of definition of moisture of the bulk material through its dielectric constant by measurement of a time elapsed for passing of a probing signal through the primary transducer inserted inside the bulk material. Precision of this moisture meter depends on deviation in measurements of a nanosecond time intervals between signal edges radiated and passed thorough the material and discarded from the reflector, which is an integral part of the measurement cell. Dispersion has its affect on deviation of the signals edge fixation, as well as depression of such signal in a material with a high moisture content that finally leads to lesser precision in measurement.

[0007] The primary transducer of this moisture meter has a complex design and is not intended for measurements directly during a technological process industrially.

CONCEPT OF THE INVENTION

[0008] The goal of this invention shall provide for:

(i) measuring the moisture content of bulk materials directly during the technological process of their reprocessing without sampling,
(ii) increased measuring precision;
(iii) simplification of a moisture meter design;
(iv) measurements' independence from materials' density at small moisture contents.

[0009] This goal was achieved by inclusion of the following components into the moisture meter for bulk materials:

a metallic hopper with sides (3) to be filled with the above-mentioned material;
a small metallic rod (4), which is installed inside the above-mentioned hopper and is fixed to openings (9, 10) formed in the walls of the hopper (3). There is a dielectric insulator (11) in the opening (9) near the first end of the above-mentioned rod between the rod and the wall of the hopper, the second end of the rod (4) is attached to the wall (3) of the hopper in such manner, so as to provide an electrical contact between them in the connection spot;

a primary transducer, formed by the outer shielding conductor (3), being in fact the above-mentioned hopper with walls (3), and a signal conductor (4), being in fact the above-mentioned rod (4), the space between which shall be filled with the above-mentioned material, the first end (8) of the rod (4) shall be the input for the above-mentioned transducer;

a probing signal generator (1) with a control input based on a frequency-tuned harmonic signal generator;

an electronic control unit (2), connected to the control input of the above-mentioned generator (1) with the capability to retune the generator (1) in the range of its operating frequencies;

a measuring cell (6), comprising a detector (17), connected to the input of the above-mentioned transducer;

a measuring device (7), connected to the above-mentioned cell (6) with the capability to determine the moisture content by frequency value, on which the minimal input resistance of the above-mentioned primary transducer is achieved.

[0010] Three options of metallic rod positioning within the hopper are suggested. The choice of a particular method is determined by assembling convenience and depends on the size and design particularities of the hopper, the placement of external bracings and also on particularities of loading and transfer of bulk material through the hopper.

[0011] The first suggested option, openings in hopper walls, in which the rod is fixed, are located on the opposite walls of the hopper in such a way that the metallic rod's axis is parallel to at least one of the hopper walls.

[0012] The second suggested option, both openings are located on the same hopper wall, the rod has a П shape and is installed in the hopper along this wall.

[0013] The third suggested option both openings are located on the same wall or on two adjacent walls of the hopper, the rod has the C shape and its axis is parallel to at least one of the hopper's walls.

[0014] Second and third options of execution and installing of the metallic rod have the following benefit as compared to the first one: the rod experiences less force impact from bulk material and is less susceptible to deformation. Besides that when loading materials with high density into the hopper (ballast, sand) the hopper walls may deform, which increases the pressure on the small metallic rod in the first option of installation. Such problem does not exist for second and third installation options, when both openings are located on the same wall.

[0015] To provide a high precision of moisture measurements one must measure not only the real component of complex dielectric conductivity (which is realized in the known moisture meter, patented as №2269766), but also the imaginary component, determined by the degree of probing signal depression within the material. In the invented moisture meter, this result is achieved in the following way: the measuring cell contains a resistor, its first terminal is connected to the generator's output, its second terminal is connected directly to the input of the primary transducer; the first detector, connected to the first terminal of the resistor and assuring measurement of resistance at the generator's output, the second detector connected to the second terminal of the resistor and assuring measurement of resistance at the primary transducer's input, the outputs of the detectors are connected to the measuring device.

[0016] For a precise moisture measurement, it is important to consider not only the value of a complex dielectric conductivity, but also the temperature of the material, in order to do so a temperature sensor can be included into the moisture meter, its output shall be connected to the measuring device.

[0017] In order to increase the precision of measuring the temperature of controlled material, an opening may be drilled inside the metallic rod at its end along its axis to install a temperature sensor inside this opening, for example, a thermal couple-based one.

[0018] To achieve a high measurement precision in the process of measurements, the bulk material must be in static condition and its quantity - the level of filling the hopper - must be stable. This requirement is followed, specifically, by installing a damper into the hopper, which closes its outlet opening, and a damper control actuator connected to the electronic switch that forms an enable signal to allow measurements and is connected to a measuring device.

[0019] The concept of the suggested technical solution is described on figures 1-8.

BRIEF DESCRIPTION OF DRAWINGS

[0020]

On fig. 1, a moisture meter for bulk materials, is described

On fig. 2, view A for the primary transducer, shown on fig.1, is described

On fig. 3, the cross section B-B of the primary transducer, shown on fig. 1, is described. Here we see an optional form of the primary transducer with a signal conductor formed as a straight metallic rod, with internally-installed temperature sensor.

On fig. 4 we see an optional form of the primary transducer, in which both openings are located on the same hopper wall, the rod has a П shape and is installed in the hopper along this wall.

On fig. 5 and 6 we see the version of the primary transducer with both openings also located on the same hopper

wall, its rod having a C shape and installed so that its axis is parallel to the second hopper wall, adjacent to the first hopper wall.

On fig. 7 a version of the primary transducer with both openings located on adjacent hopper walls, it has a C-shape rod and is installed so that its axis is parallel to the third hopper wall, for example, formed by a damper, is described

On fig. 8 we can see the measuring cell.

REALIZATION OF THE INVENTION

[0021] The moisture meter for bulk materials comprises a probing signal generator 1, an electronic control unit 2, a primary transducer formed by an outer shielding conductor 3 and a signal conductor 4, inter-space of which are filled with a material to be measured 5, a measuring cell 6 and a measuring device 7. The input of the generator 1 is connected to the electronic control unit 2. A measuring cell 6 is installed between the generator's output 1 and an input 8 of the primary transducer. The measuring device 7 is connected to the electronic control unit 2 and the measuring cell 6.

[0022] The probing signal generator 1 is based on a frequency-tuned harmonic signal generator. A metallic hopper with bulk material to be measured inside serves as the outer shielding conductor. A signal conductor 4 formed as a small metallic rod is installed inside the hopper, and is fixed in openings 9 and 10 located on the walls of the 3 hopper. There is a dielectric insulator 11, installed inside an opening 9 near the first end of the small metallic rod 4 acting as the input 8 of the primary transducer, between the rod 4 and the wall 3. A metallic rod 4 is connected to the wall 3 of a metallic hopper by its second end inside the opening 10 or near the opening 10, therefore providing an electrical contact in the connection spot.

[0023] The hopper contains the damper 12, which closes the outlet opening of the hopper and a damper control actuator 13. A damper control actuator 13 is connected to the electronic switch 14 that forms an enabling signal to allow measurements if the damper 12 is closed, and is connected to the measuring device 7.

[0024] A measuring cell 6 contains a resistor 15, its first terminal is connected to the output of the generator 1 and its second terminal is connected to the input 8 of the primary transducer; the first detector 16, which is connected to the first terminal of the resistor 15 and the second detector 17, which is connected to the second terminal of the resistor 15. Outputs of detectors are connected to a measuring device 7.

[0025] The moisture meter can also include a temperature sensor 18 for the bulk material 5, an output of the sensor 18 shall be connected to the measuring device 7. In the end (end face) of the small metallic rod 4 along its axis, there is an opening 19 with a temperature sensor 18, for example, a thermal couple-based one, inside it.

[0026] The operating principle of this moisture meter is based on measuring the moisture content of a bulk material by its complex dielectric conductivity: both real and imaginary components of this parameter are being measured. The moisture content value of this material is computed taking into account the temperature of this material.

[0027] The complex dielectric conductivity of the material is determined on the basis of measuring the following parameters:

- resonant frequency of the primary transducer, determined at retuning the harmonic signal generator, in accordance with the minimal input resistance of the primary transducer, filled with bulk material;
- input resistance at the resonant frequency of the primary transducer, filled with bulk material.

[0028] The moisture meter operates in the following manner. The electronic control unit 2 retunes the generator 1 within the range of operating frequencies. Simultaneously with the retuning procedure, the voltage values at first and second outputs of the resistor 15 of the measuring cell 6 are being measured. Semiconductor detectors 16 and 17, converting highfrequency signals into low-frequency signals, are used for measurements. U_{16} and U_{17} voltage values, registered, correspondingly, at the first 16 and the second 17 detector outputs, are forwarded to the input of the measuring device 7. U_{17} to U_{16} voltage ratio is determined in the measuring device 7. The minimal (U_{17}/U_{16}) voltages ratio is achieved when the input voltage of the primary transducer is minimal. Using the measured value of this ratio and the known resistance value of the resistor 15, the measuring device 7 calculates the value of this resistance. When the minimal value is reached, the harmonic signal frequency, produced by the generator 1, is determined and recorded. This frequency (if the geometric length of the signal conductor is known) allows to calculate the electromagnetic wave deceleration in the controlled material, because at the moment of minimal input resistance the length of the primary transducer "accommodates" an integral number of half-waves. Then the complex dielectric conductivity is determined by the calculated value of input resistance, taking into account the deceleration ratio. Computations of mass content of moisture in a particular bulk material are performed with the help of conversion tables, composed for a set of temperatures and put into the processor's memory. The final result is transmitted from the output of the measuring device 7 via a digital interface (for example, RS485) or a current signal 4-20 mA to an external indicator or an industrial controller, managing the technological process.

[0029] It is worth noticing that the suggested moisture meter can offer two options of the measuring process.

[0030] First option: a generator 1 is tuned frequency-wise by the control device 2 in such manner, that the (U_{17}/U_{16}) ratio for signals at the output of the measuring cell 6 is minimal, when the minimal value is reached, the measuring device 7 measures the frequency of the probing signal frequency and the value of the input resistance of the primary transducer.

[0031] Second option: a measuring device 7 measures the (U_{17}/U_{16}) ratio for a line of frequencies from the frequency range around the minimal point, therefore, the full frequency characteristic of input resistance of the primary transducer is being recorded.

[0032] It is worth noticing that the electronic control unit 2 of a frequency-tuned harmonic signal generator 1 can be executed in two options:

- as a synthesizer, forming the frequency of the generator by the digital code, generated by the measuring device 7, comprising a processing unit;
- as an analog cascade, retuning the generator 1 until the minimal signal ratio (U_{17}/U_{16}) is reached, in this case the measuring cell 6 and the measuring device 7 must comprise probing signal frequency measuring units.

[0033] To increase the precision of the measuring process, the damper 12 should be in closed position. The electronic switch 14, sent to the input of the measuring device 7, forms a measurement-enabling signal. The electronic switch is connected to the damper control actuator 13. The moment of the formation of a measurement-enabling signal is determined by modes of loading and emptying of the hopper.

[0034] If hopper is constantly loaded with bulk material and the damper 12 is opened only for sending a portion of this material into the hopper below, measurements can start with a small delay after the damper 12 is closed, and continue unless the damper is not closed.

[0035] If the hopper is used as a weighing device for accumulation of a predetermined mass of the bulk material with further opening of the damper 12, then moisture content measurements must start before the opening of the damper 12 and finish at its opening.

[0036] The conducted tests have confirmed the effectiveness of the suggested technical solution.

Claims

1. Moisture meter for bulk materials (5), comprising:

   a metallic hopper with walls (3), designed for being filled with the above-mentioned material;
   a metallic rod (4), installed inside the above-mentioned hopper and fixed in the openings (9, 10), made in the above-mentioned walls (3), while a dielectric insulator (11) is installed in the opening (9) near the first end of the above-mentioned rod between this bar and the wall of the above-mentioned hopper, the second end of the rod (4) is connected to the wall (3) of the hopper to form an electrical contact in the connection spot;
   a primary transducer, formed by the outer shielding conductor (3), being in fact the above-mentioned hopper with walls (3), and a signal conductor (4), being in fact the above-mentioned rod (4), the space between which shall be filled with the above-mentioned material, the first end (8) of the rod (4) shall be the input for the above-mentioned transducer;
   a probing signal generator (1) with a control input based on a frequency-tuned harmonic signal generator;
   an electronic control unit (2), connected to the control input of the above-mentioned generator (1) with the capability to retune the generator (1) in the range of its operating frequencies;
   a measuring cell (6), comprising a detector (17), connected to the input of the above-mentioned transducer;
   a measuring device (7), connected to the above-mentioned cell (6) with the capability to determine the moisture content by frequency value, on which the minimal input resistance of the above-mentioned primary transducer is achieved.

2. The moisture meter as per article 1, **characterized by** the fact that the openings (9, 10), in which the above-mentioned rod is fixed, are located on the opposite walls (3) of the hopper.

3. The moisture meter as per article 1, **characterized by** the fact that the openings (9, 10), in which the above-mentioned rod (4) is fixed, are located on the same wall (3) of the above-mentioned hopper, the rod has the П shape and is installed in the hopper along the above-mentioned wall (3).

4. The moisture meter as per article 1, **characterized by** the fact that the openings (9, 10), in which the above-mentioned rod (4) is fixed, are located on the same wall (3) or on two adjacent walls of the above-mentioned hopper, the rod

has the C shape and its axis is parallel to at least one of the walls (3) of the above-mentioned hopper (3).

5. The moisture meter as per any of 1-4 articles, **characterized by** the fact, that it comprises a temperature sensor (18), installed inside the opening (19), located at the end of the above-mentioned rod (4) and drilled along the axis of this bar.

6. The moisture meter as per any of 1-4 articles, **characterized by** the fact, that its above-mentioned measuring cell comprises a resistor (15), its first terminal is connected to the output of the above-mentioned generator (1) and the detector (16) and its second terminal is connected to the above-mentioned input of the primary transducer; the outputs of detectors 16 and 17 are connected to the above-mentioned measuring device (7).

7. The moisture meter as per article 6, **characterized by** the fact, that it additionally comprises a temperature sensor (18), installed inside the opening (19), located at the end of the above-mentioned rod (4) and drilled along the axis of this bar.

8. The moisture meter as per article 1, **characterized by** the fact, that its above-mentioned hopper additionally comprises a damper (12) with the capability to close off its outlet opening and a damper control actuator (13), connected to an electronic switch (14) forming the signal to allow measurements and connected to the above-mentioned measuring device.

9. Moisture meter as per article 1, **characterized by** the fact that its above-mentioned control device (2) is in the form of a synthesizer, forming the frequency of the generator (1) by the digital code, generated by the measuring device (7), comprising a processing unit.

10. Moisture meter as per article 1, **characterized by** the fact that its above-mentioned control device (2) is in the form of an analog cascade, retuning the generator (1) until the minimal signal ratio (U_{17}/U_{16}) is reached, while the measuring device (7) must comprise a probing signal frequency measuring unit.

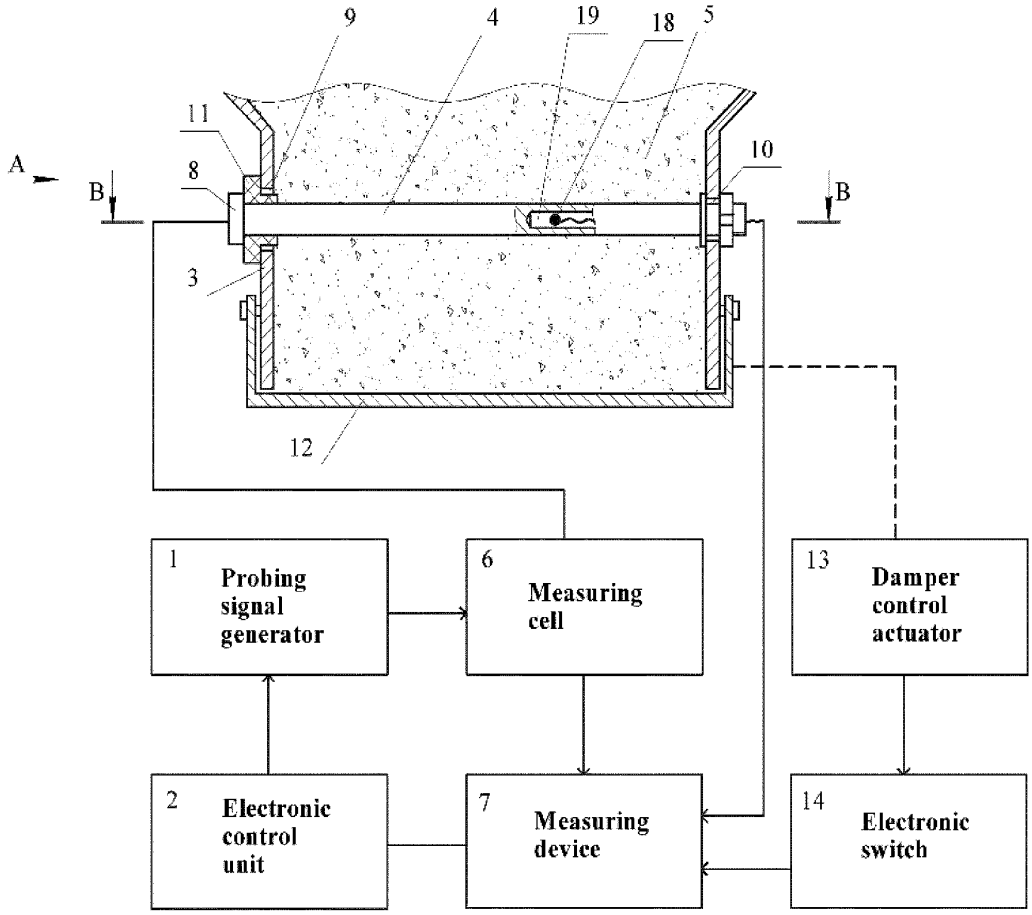
9
4
19
18
5
11
10
A
B
8
B
3
12
1
Probing signal generator
6
Measuring cell
13
Damper control actuator
2
Electronic control unit
7
Measuring device
14
Electronic switch

Fig. 1

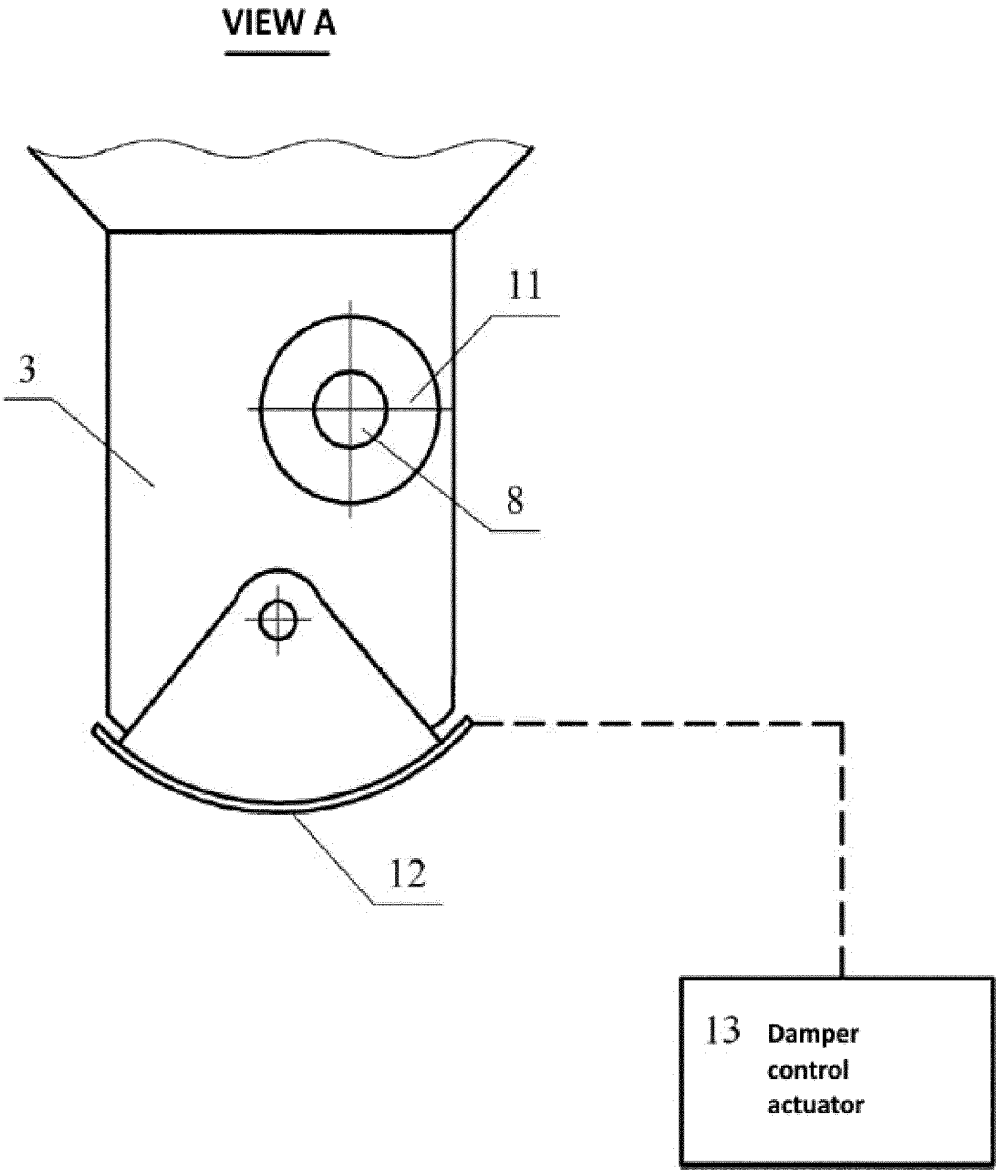

Fig. 2

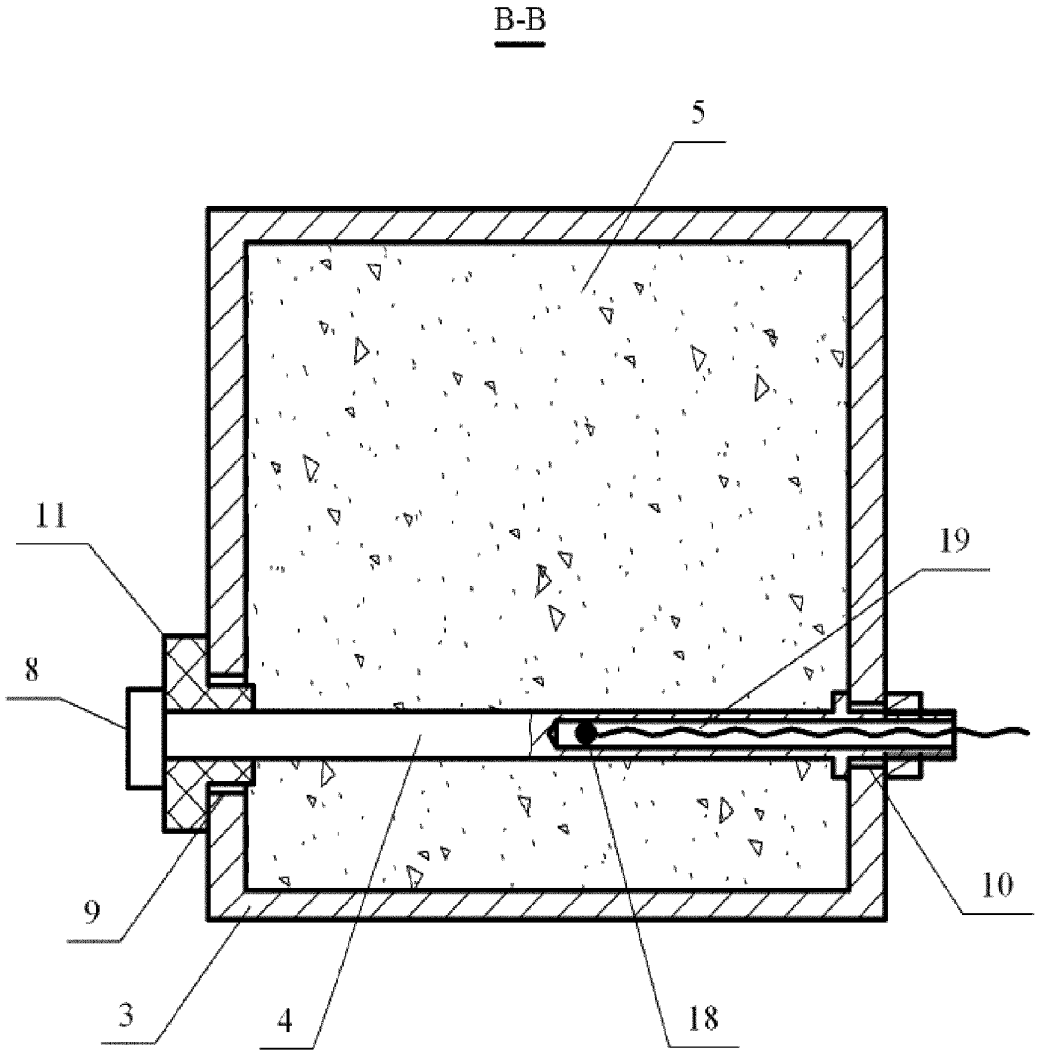

Fig. 3

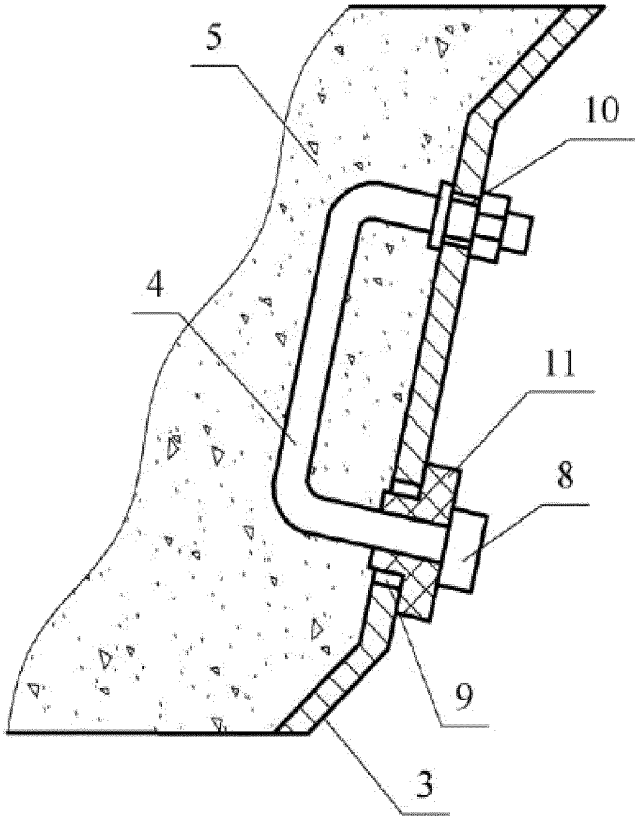

Fig. 4

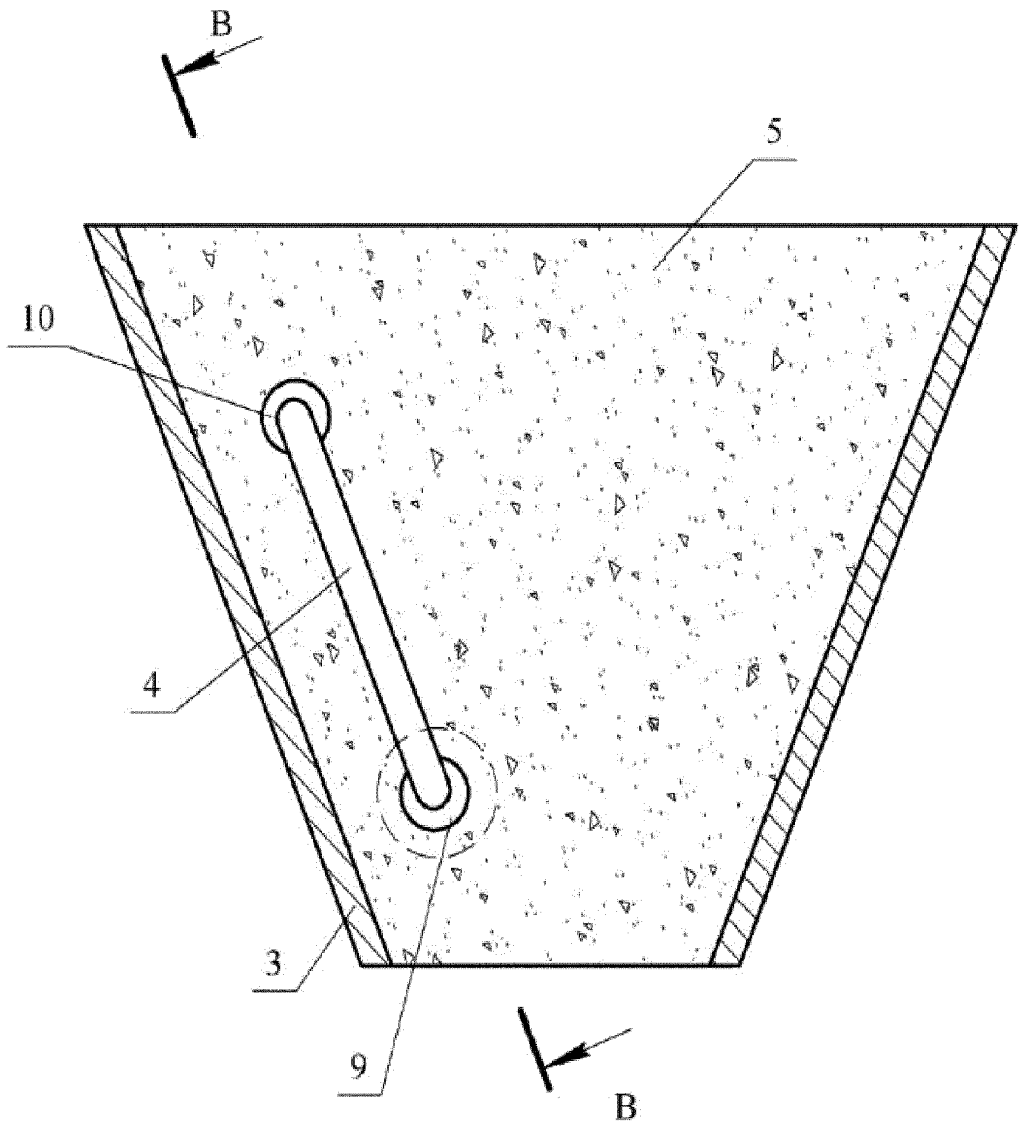

Fig. 5

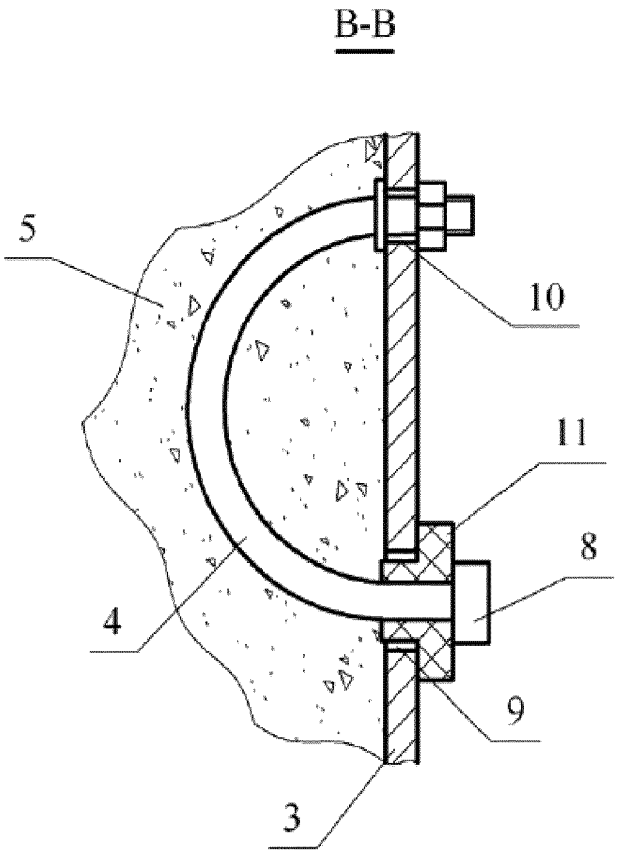

Fig. 6

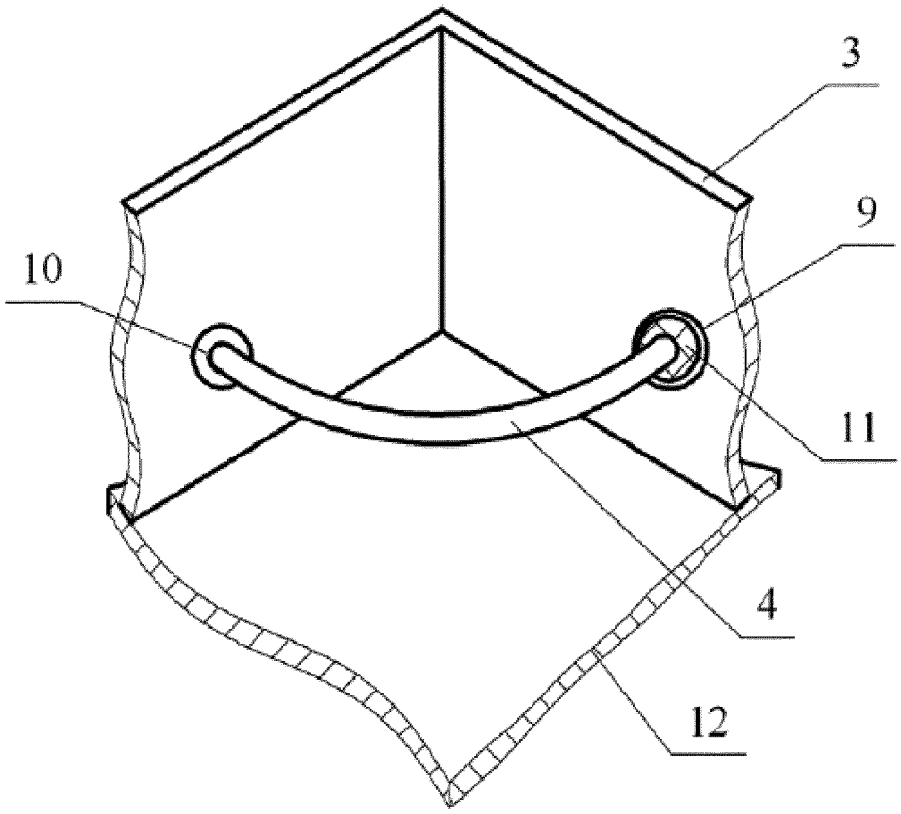

Fig. 7

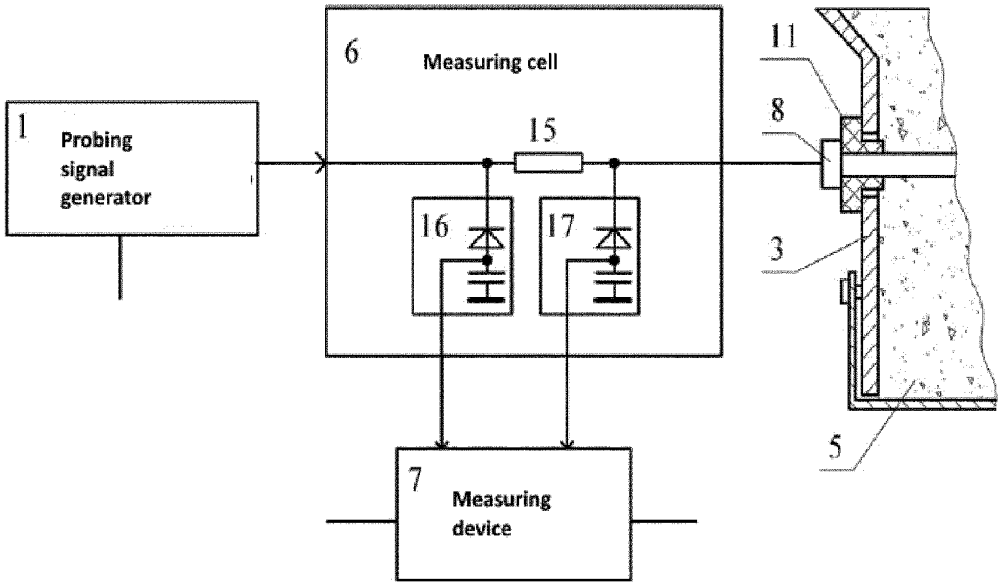
1
Probing signal generator
6
Measuring cell
15
16
17
11
8
3
5
7
Measuring device

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2013/001001

A. CLASSIFICATION OF SUBJECT MATTER
G01N 22/04 *(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N 22/00-22/04, 29/12, F26B 25/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSearch (RUPTO internal), Espacenet, PAJ, USPTO, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2269766 C2 (FEDERALNOE GOSUDARSTVENNOE UNITARNOE PREDPRYIATIE NAUCHNO-ISSLEDOVATELSKY INSTITUT SELSKOKHOZIYAISTVENNYKH PRIBOROV MINISTERSTVA SELSKOGO KHOZIYAISTVA ROSSYSKOI FEDERATSII) 10.02.2006, abstract, fig. 1-2, the claims, p. 5, lines 11-40, p. 6, lines 1-30	1-10
A	RU 2277212 C1 (OTKRYTOE AKTSIONERNOE OBSHCHESTVO "TVERSELMASH") 27.05.2006, abstract, fig. 1, the claims	1-10
A	RU 2096768 C1 (PROIZVODSTVENNO-KOMMERCHESKAIA FIRMA "VEST KOMPANI LIMITED") 20.11.1997, abstract, p. 4, lines 30-57	1-10
A	US 5212453 A (IMKO MICROMODULTECHNIK GMBH) 18.05.1993, abstract, fig. 1, 6-7	1-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 April 2014 (24.04.2014)	07 Mai 2014 (07.05.2014)
Name and mailing address of the ISA/ RU	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- WO 2269766 A **[0015]**

Non-patent literature cited in the description

- **BENZAR V. K.** *Technology of UHF moisture measurement. - Minsk: Vysshaya shkola,* 1974, 226-234 **[0002]**

EP2921848 (A4) — 2016-06-29

MOISTURE METER FOR BULK SOLIDS

Page bookmark	EP2921848 (A4) - MOISTURE METER FOR BULK SOLIDS
Inventor(s):	[RU]; SIZIKOV OLEG KREONIDOVICH [RU]; KONNOV VLADIMIR VALERIEVICH [RU]; SILAEV KONSTANTIN VLADIMIROVICH [RU]; SEMENOV ANDREY SERGEEVICH [RU] RAGAZIN DENIS NICOLAEVICH +
Applicant(s):	[DE]; PCE DEUTSCHLAND GMBH [RU] DESIGN BUREAU FIZELEKTRONPRIBOR LTD +
Classification:	**- international:** ***G01N22/04*** **- cooperative:** **G01N22/04**
Application number:	EP20130854958 20131111 Global Dossier
Priority number(s):	RU20120148490 20121114 ; WO2013RU01001 20131111
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Abstract of EP2921848 (A1)

The moisture meter for measuring the moisture content of bulk solids comprises a harmonic signal generator which is retuneable in terms of frequency and the control input of which is connected to an electronic control device, a primary transducer formed by an outer shielding conductor and a signal conductor, with the space between said conductors being filed with the material to be measured, a measuring cell which is included between the output of the generator and the input of the primary transducer, and a measuring device which is connected to the control device and the measuring cell. The outer shielding conductor of the primary transducer used is a metallic hopper. The signal conductor is in the form of a small metallic bar, which is mounted inside the hopper and is fixed in openings formed in the walls of said hopper. An insulator consisting of a dielectric is mounted in an opening at a first end of the small bar, and the small bar is connected at its second end to the wall of the hopper. The moisture meter measures the moisture content of bulk solids without taking samples, and ensures an increased level of accuracy and insensitivity to variations in the density of the material at low moisture content levels.